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Cocconeis tortilis: a new marine diatom (Bacillariophyta, Cocconeidaceae) from Japan

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Abstract

A new species of *Cocconeis*, *C. tortilis*, was found on some seaweed collected from the Izu and Okinawa Islands of Japan. Its morphology was examined using both light and electron microscopy; details are described herein. This small diatom is characterized by: 1) a concave raphid valve with a straight raphe inclined from the apical axis, central area forming stauros, and uniseriate striae consisting of circular areolae occluded by hymens: 2) a twisted convex araphid valve with a narrow lanceolate sternum inclined from the apical axis, and uniseriate striae consisting of several loculate areolae occluded by hymens: and 3) a cingulum consisting of three non fimbriated girdle bands including a valvocopula.

Key words: Bacillariophyta, *Cocconeis tortilis*, Japan, marine diatom, new species

Introduction

This report is a continuation of our previous papers dealing with morphological and taxonomic investigations of species in the genus *Cocconeis* (Ehrenberg 1837: 173; Nagumo & Kobayasi 1985, Suzuki *et al.* 2001). In the present study, an unrecognized species of *Cocconeis* was found growing on seaweed (e.g. *Codium intricatum* Okamura 1913: 74) and the seagrass *Zostera japonica* Ascheron & Graebner (1907: 32) from the coasts of Izu Islands, Minami-Daito Island and Okinawa Islands, both affected by the Kuroshio Current. It has been named *C. tortilis* Hide. Suzuki *sp. nov.* and is described using light (LM), scanning and transmission electron microscopy (SEM and TEM); it is compared to similar taxa.

Material and methods

Samples were obtained from seaweeds and seagrass collected from the intertidal zone of the North Pacific coast of Japan at the following localities (Fig. 1):

I. Tsuchikata beach (34°04’20”N, 139°28’41”E), Miyake Island, the Izu Islands, Tokyo, epiphytic on *Codium intricatum* (Codiaceae, Ulvophyceae) collected by A. Takahashi on 3 July 2012, material and slide BM 101683 and MTUF-AL-43010;

II. Shioma beach (33°04’06”N, 139°50’07”E), Hachijo Island, the Izu Islands, Tokyo, epiphytic on *Asparagopsis taxiformis* (Delie) Trevisan (Bonnemaisoniaceae, Rhodophyceae) collected by A. Kobayashi on 28 June 2003, material MTUF-AL-43011;

III. Honba beach (25°52’19”N, 131°14’58”E), Minami-Daito Island, the Daito Islands, Okinawa Pref., epiphytic on *Jania* sp. (Corallinaceae, Rhodophyceae) collected by T. Nagumo on 17 Feb. 2004, material MTUF-AL-43012;

IV. Eef beach (26°19’54”N, 126°48’39”E), Kume Island, the Okinawa Islands, Okinawa Pref., epiphytic on the

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seagrass *Zostera japonica* (Zosteraceae, Liliopsida) collected by Y. Mikame on 31 May 2010, material MTUF-AL-43013; and

V. Shinri Beach (26°21'18"N, 126°42'50"E), Kume Island, the Okinawa Islands, Okinawa Pref., epiphytic on *Boodlea coacta* (Dickie) G.Murray & De Toni (Boodleaceae, Ulvophyceae) collected by Y. Mikame on 31 May 2010, material MTUF-AL-43014.

Samples and type slides were deposited at BM (BM 101683) and the Algae Collections of the Museum of Fishery Sciences, Tokyo University of Marine Science and Technology, Japan (MTUF-AL-43010-43014).

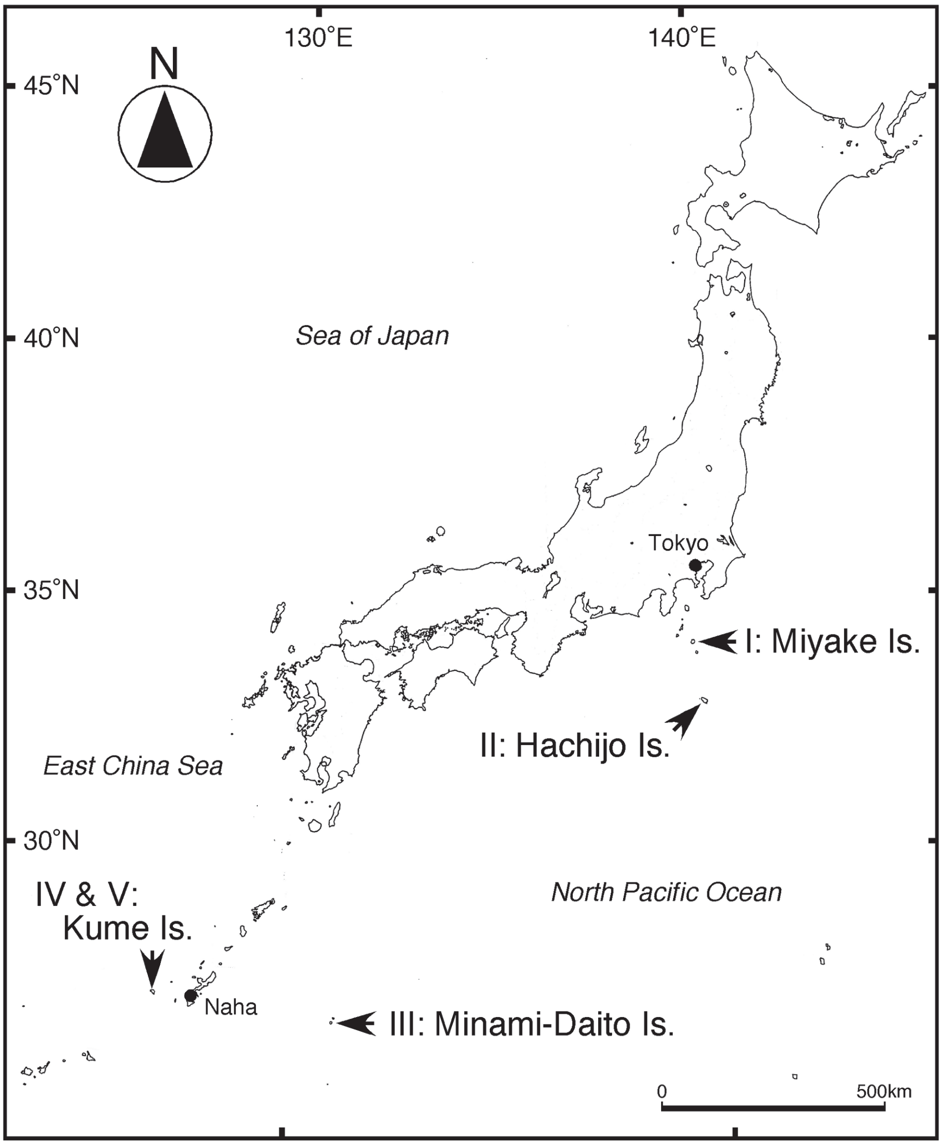


FIGURE 1: Map of the 5 sampling sites in the North Pacific coast of Japan (arrows). Numbers (I–V) correspond to those in text.

All samples were fixed with 2.5 % glutaraldehyde solution.

The material was treated using the bleaching method described by Nagumo & Kobayasi (1990), Nagumo (1995) and Osada & Nagumo (2001). Light and electron microscopy techniques are described in Nagumo & Kobayasi (1985) and Suzuki *et al*. (2001). Prepared specimens were examined using HITACHI S-5000 SEM and JEOL-2000EX TEM (The Nippon Dental University School of Life Dentistry at Tokyo) operating at 2kVand 80 kV, respectively.

The valves' size was determined from measurements of 30 valves; striae density was measured in 15 valves using TEM as the striae are difficult to observe accurately by LM.

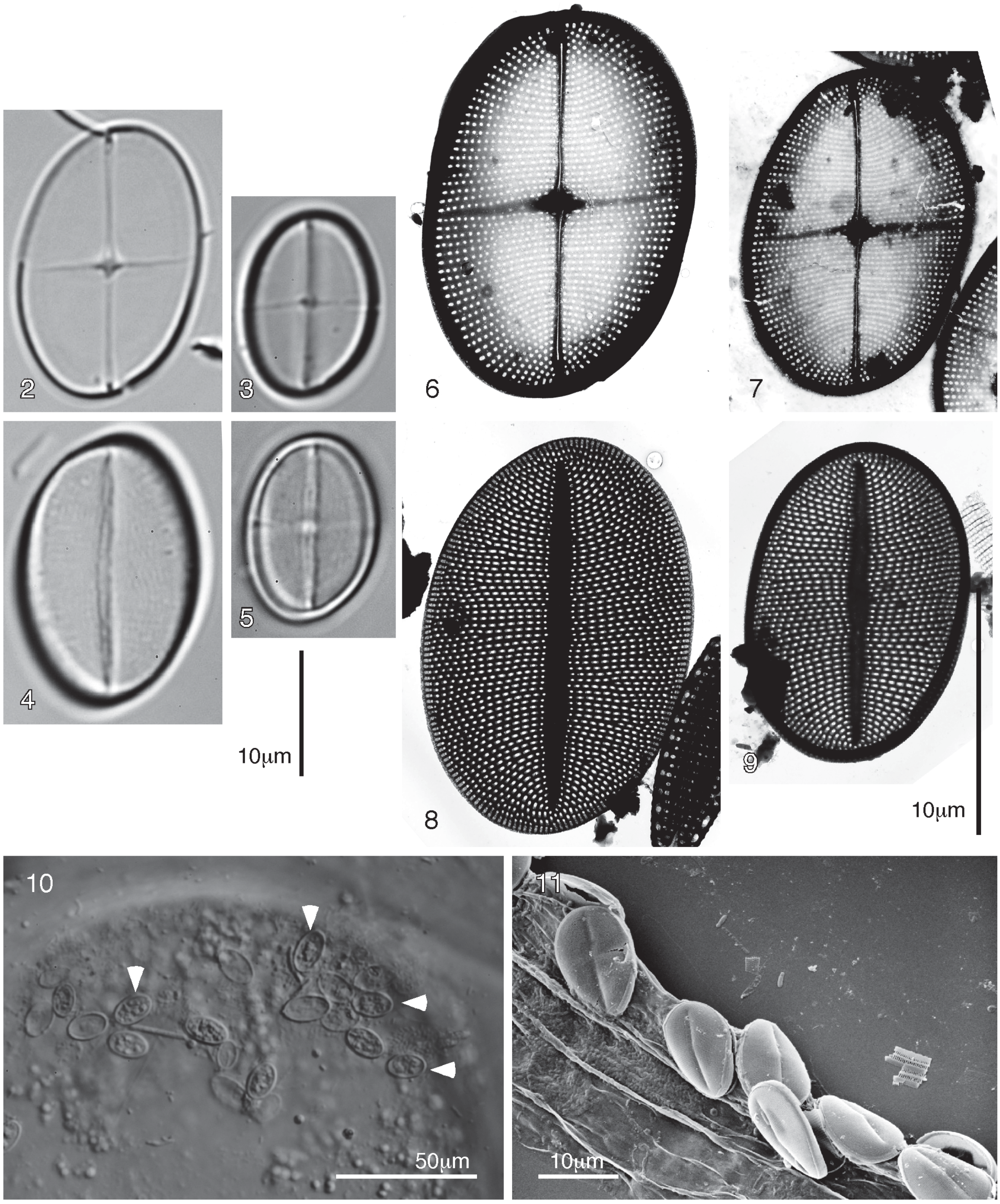
The terminology for the parts of the valve and girdle follow Anonymous (1975), Ross *et al.* (1979) and Cox (2012), with additional terms from Kobayasi *et al.* (2006).

New species description

Division **Bacillariophyta**
Class **Bacillariophyceae**
Order **Achnanthales** Silva 1962
Family **Cocconeidaceae** Kützing 1844
Genus ***Cocconeis*** Ehrenberg 1837

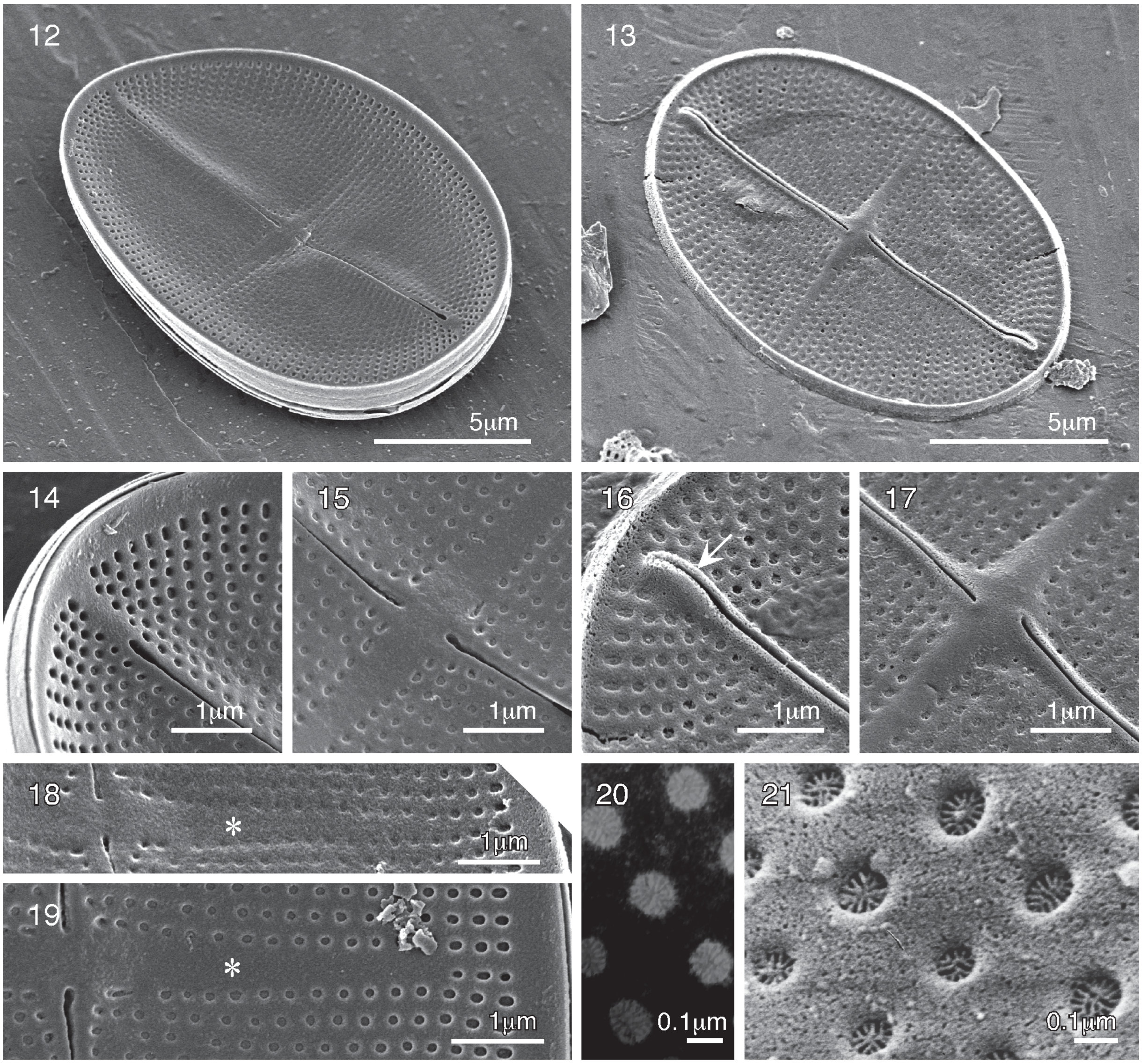
Cocconeis tortilis Hide. Suzuki**, *sp. nov.*** (Figs 2–35)

Type:—JAPAN. Tsuchikata beach (34°04'20"N, 139°28'41"E), Miyake Island, the Izu Islands, Tokyo, collected from surface of *Codium intricatum* on 3rd July 2012 (holotype! BM 101683, **designated here** = Figs 2, 4; isotype! MTUF-AL-43010, **designated here**, the Algae Collections of the Museum of Fishery Sciences, Tokyo University of Marine Science and Technology, Japan.



FIGURES 2–11: *Cocconeis tortilis*. LM (2–5), TEM (6–9) and SEM (10, 11), holotype and other specimens. Figs 2–5: Focused for raphid valves (RV) (Figs 2, 3) and araphid valves (ARV) (Figs 4, 5) of the same frustule. Figs 2, 4: Specimens from holotype slide. Figs 6–9: RV (Figs 6, 7) and ARV (Figs 8, 9). Fig. 10: *C. tortilis* (arrowheads), epiphytic on *Codium intricatum*. Fig. 11: *C. tortilis*, epiphytic on *Asparagopsis taxiformis*.

The frustule is heterovalvate. The valve is small, elliptic to oval, and twisted (Figs 2–9), measuring 10.4–17.2 μm in length, 7.2–11.6 μm in breadth. Striae densities at the centre of the valves are 33–45 in 10 μm for the raphid valve (RV), 43–55 in 10 μm for the araphid valve (ARV). The RV is slightly concave (Fig. 12). The raphe is straight, and inclined from the apical axis (Figs 2, 3, 6, 7). The inner raphe lie in a very narrow, but raised, axial area (Fig. 13). The proximal raphe ends are coaxial and slightly-dilated externally (Fig. 15) but internally they are undilated and deflected in opposite directions (Fig. 17). The distal raphe ends are elliptically-dilated externally (Fig. 14) but, internally, terminate in short helictoglossae (Fig. 16, arrow). The central area is rhombic in shape (Figs 6, 7) and extending laterally to the valve margin in one stria's width (Figs 12, 13, 18, 19). This area is flat on the outer surface (Figs 15, 18, 19) and slightly raised on the inner surface (Figs 13, 17), forming a stauros (Figs 18, 19, asterisks). The striae consist of small round areolae, and are radiate and uniseriate (Fig. 12). Each areola is circular and occluded by a hymen with perforations arranged in a centric array (Figs 20, 21). A submarginal hyaline area is not recognizable; a narrow marginal hyaline area is visible (Fig. 12). The terminal hyaline area is small and elliptical, and extends to the marginal hyaline one (Figs 12, 14).



FIGURES 12–21: *Cocconeis tortilis*, SEM (12–19, 21) and TEM (20), raphid valves (RV). Figs 12, 14, 15, 18, 19, 21: External views. Figs 13, 16, 17: Internal views. Figs 12, 13: Whole valves. Figs 14, 16: Distal raphe ends in terminal area. Arrow indicates helictoglossa. Figs 15, 17: Proximal raphe ends in central area. Figs 18, 19: Central areas extending laterally to the valve margin, forming the stauros (asterisks). Figs 20, 21: Areolae occluded by the hymenes with linear perforations in a centric array.

The ARV is convex (Fig. 22) and twisted (Figs 11, 34). The ARV (Fig. 23) is thicker than the RV (Fig. 13). The sternum, inclined from the apical axis (Fig. 35, dashed line), is a narrow furrow on the outer surface (Fig. 22), and narrow lanceolate internally (Figs 8, 9, 23). In some valves, a vestigial raphe is observed (Fig. 25, arrows). The striae that consist of several loculate areolae (Fig. 24) are radiate and uniseriate (Fig. 22). Each areola is occluded by a hymen located near the outer surface (Fig. 28, arrows), internally, opens by means of a circular to elliptic foramen (Figs 23, 25). The perforations of the hymen are linear, oblique and arranged in a parallel array (Figs 26, 27).

The mature cingulum consists of three girdle bands (Figs 29, 30): a valvocopula and two bands (the second and the third bands), which are both narrower and thinner than the valvocopula. The valvocopula of each valve is open at one pole (Figs 31–33, arrows) and has no fimbriae and areolae; their inner edges are smooth (Figs 31, 33). The second band, adjacent to the valvocopula, is open at the opposite pole (Fig. 30) and possesses a ligula (Fig. 29). The third band is also open (Fig. 29). The valvocopula of each valve is open at a place slightly shifted from one distal end of the raphe or sternum (Figs 31–35, arrows). This is similar to the second and third bands; the disordered of arrangement of striae, known as the "Voigt fault" (Voigt 1956) can be observed here (Figs 29, 30, arrows).

Etymology:—From the Latin *tortilis* (twisted), referring to the twisted appearance of the valve plane.

Distribution and ecology:—*Cocconeis tortilis* has been found in the Izu, Daito, and Okinawa Islands affected by the Kuroshio Current, which is a north-flowing warm ocean current on the west side of the North Pacific Ocean, and grows abundantly on the spherical utricles of *Codium intricatum* in Miyake Island, Japan (Fig. 10, arrowheads) and on the fine branches of *Asparagopsis taxiformis* in Hachijo Island, Japan (Fig. 11).

Observations:—*Cocconeis tortilis* has the following characteristics of the genus (after Round *et al*. 1990):

1) heterovalvar; one valve (RV) with a raphe, the other (ARV) without;
2) valves elliptical or almost circular;
3) RV concave with a correspondingly convex ARV;
4) areolae occluded by hymens with linear perforations;
5) terminal raphe endings without fissures;
6) central raphe endings externally simple or slightly expanded, internally deflected towards opposite sides; and
7) cingulum consisting of a few narrow, non-areolae bands.

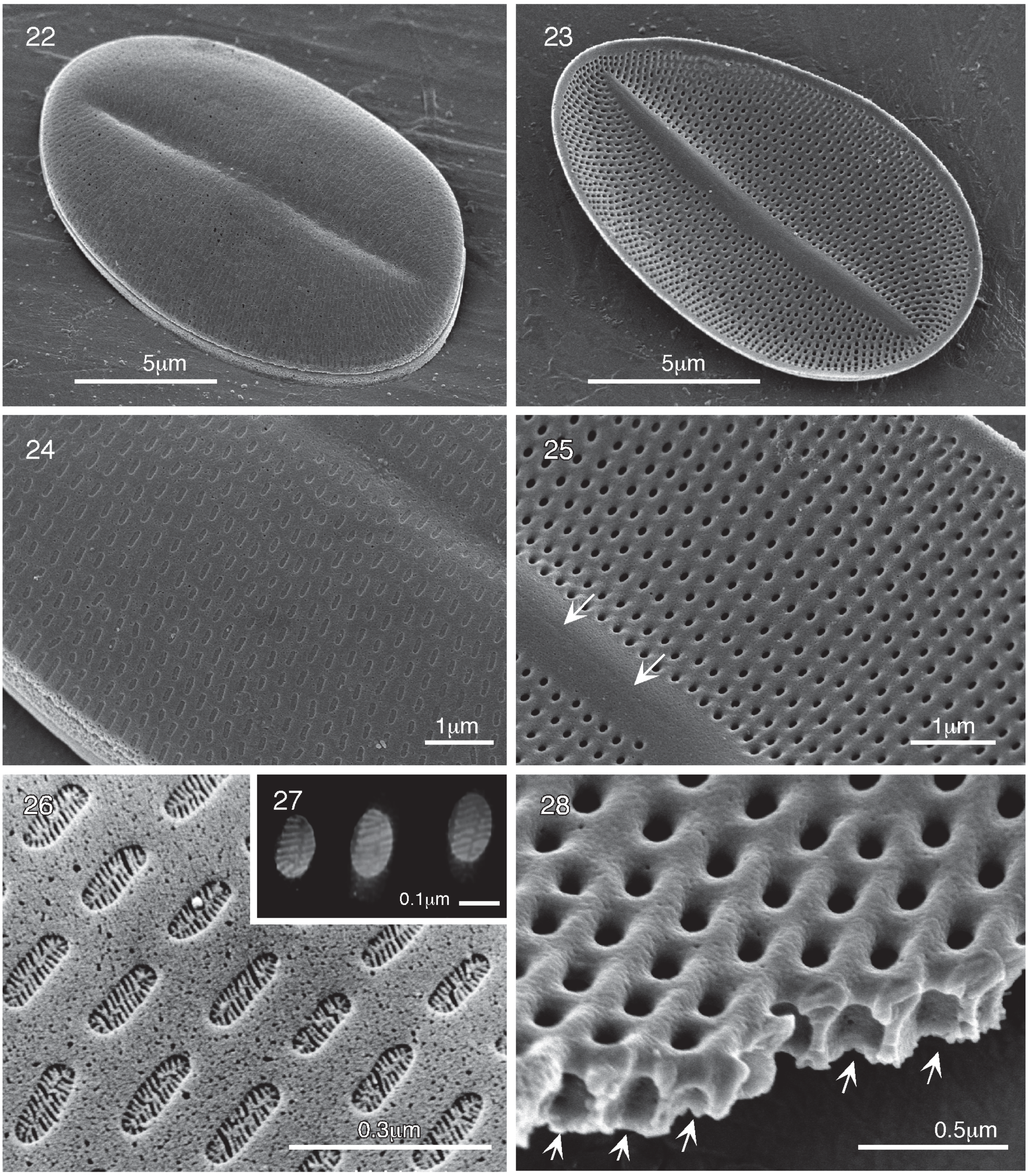
Our study suggests that *C. tortilis* is most similar to *C. molesta* Kützing var. *crucifera* Grunow (in Van Heurck 1880–1885: pl. 30, figs 20–23; Kobayasi & Nagumo 1985, De Stefano *et al*. 2000), *C. dirupta* Gregory (1857: 491; Kobayasi & Nagumo 1985), and *C. convexa* Giffen (1967: 257; Suzuki *et al*. 2001, De Stefano & Romero 2005), but can be distinguished from each other by several characters (listed in Table 1).

TABLE 1. Comparison of *Cocconeis tortilis* with *C. molesta* var. *crucifera*, *C. dirupta* and *C. convexa* in morphological attributes.

Characteristics	*C. tortilis*[a]	*C. molesta* var. *crucifera*[b, c, e]	*C. dirupta*[b]	*C. convexa*[d, f]
Apical axis (μm)	10.4–17.2	[b]18.0, [c]16.0–18.0, [e]12.0–21.0	14.0–30.0	[d]14.5–22.5, [f]14.0–30.0
Transapical axis (μm)	7.2–11.6	[b]7.0, [c]7.5–9.0, [e]8.5–16.0	9.0–23.0	[d]12.0–17.0, [f]8.6–20.0
Valve shape	Elliptic to oval	Broad elliptic	Broad elliptic to elliptic	Rhombic to elliptic
Raphid valve				
Density of striae in 10 μm	33–45	[b]30, [c]28–30, [e]20–30	22	[d]24–28, [f]30–34
Shape of raphe	Straight	Straight	Sigmoid	Straight
Central area	Stauros	Not stauros	Stauros	Not stauros
Position between raphe and apical axis	Inclined	Not inclined	Not inclined	Not inclined
Araphid valve				
Density of striae in 10 μm	43–55	[b]38, [c]35–37, [e]n.d.	20	[d]36–40, [f]34–38
Curvature of valve	Convex and twisted	Strongly convex	Convex	Strongly convex
Shape of sternum	Narrow lanceolate	Not lanceolate, linear	Sigmoid, lanceolate	Narrow lanceolate
Position between sternum and apical axis	Inclined	Not inclined	Not inclined	Not inclined
Structure of areola	Loculate	Loculate	Loculate	Alveolate
Occlusion of areola	Elongate hymen	Two horseshoe shaped	Elongate hymen	Elongate hymen
Arrangement of hymen perforations	Parallel array	Parallel array	Parallel array	Parallel array
Girdle bands				
Fimbriae and areolae	None	None	None	None
Inner edge	Smooth	Smooth	Smooth	Smooth

[a]This study, [b]Kobayasi and Nagumo (1985), [c]De Stefano et al. (2000), [d]Suzuki et al. (2001), [e]Sar et al. (2003), [f]De Stefano and Romero (2005), n.d.: no data.

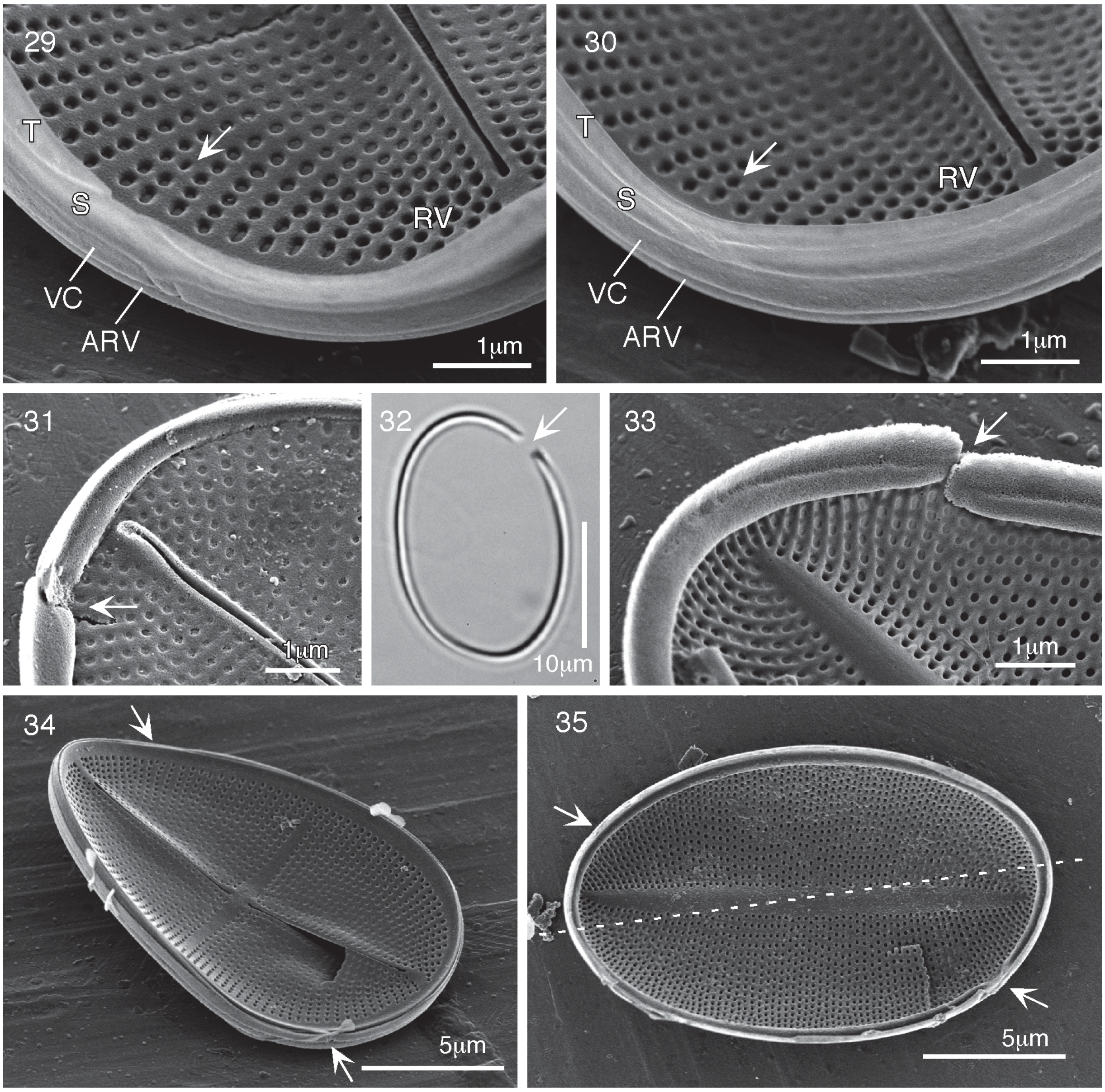
Cocconeis tortilis has the following unique characters:
1. The ARV plane is twisted; and
2. the raphe in the RV and the sternum in the ARV are inclined from the apical axes.



FIGURES 22–28: *Cocconeis tortilis*, SEM (22–26, 28) and TEM (27), araphid valves (ARV). Figs 22, 24, 26: External views. Figs 23, 25, 28: Internal views. Figs 22, 23: Whole valves. Figs 24, 25: Valves between the axial and marginal area. Figs 26, 27: Areolae occluded by the hymenes with perforations in a parallel array. Fig. 28: Loculate areolae occluding by hymenes (arrows) located near the outer surface.

These characters have not been observed in any other species of *Cocconeis*, and are thus diagnostic for *Cocconeis tortilis*. *C*. *tortilis* can be readily distinguished from *C*. *molesta* var. *crucifera* in having a central area not forming stauros in the RV, in having an areola occluded by two 'horseshoe shaped' hymens and a linear sternum of ARV and in having a lower density of the striae on both valves (30, 28–30 in 10 μm on the RV, 38, 35–37 in 10 μm on the ARV; Kobayasi & Nagumo 1985, De Stefano *et al*. 2000, respectively); it can be distinguished from *C*.

dirupta in having a sigmoid raphe of RV, in having a sigmoid sternum of ARV and in having a lower density of the striae on both valves (22 in 10 µm on the RV, 20 in 10 µm on the ARV; Kobayasi & Nagumo 1985); it can be distinguished from *C. convexa* in having a central area not forming stauros of RV, in having an alveolate areola of ARV and in having a lower density of the striae on both valves (24–28, 30–34 in 10 µm on the RV, 36–40, 34–38 in 10 µm on the ARV; Suzuki *et al*. 2001, De Stefano & Romero 2005, respectively).



FIGURES 29–35: *Cocconeis tortilis*, SEM (29–31, 33–35) and LM (32), cingula. Fig. 29: Valvocopula (VC), and the second (S) and the third (T) bands of ARV. Fig. 30: Opposite pole. Arrows indicate the disorder of arrangement of striae. Figs 31, 33: Internal views of the poles of RV and ARV with valvocopula (VC), respectively. Arrows indicate the open parts of valvocopula. Fig. 32: Valvocopula of ARV. Arrow indicates the open part of valvocopula. Figs 34, 35: Open parts (arrows) of each band of ARV. Note that the sternum is inclined from the apical axis (dashed line).

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